Resection of a large, high-flow arteriovenous malformation during hypotension and hypothermia induced by a percutaneous cardiopulmonary support system

Case report

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We have used the percutaneous cardiopulmonary support system (PCPS) to maintain hypotension and mild hypothermia during resection of cerebral arteriovenous malformations (AVMs) is control of bleeding and cerebral swelling. Induced hypotension is one of the most valuable means of achieving this control. The authors introduced induced hypotension with mild hypothermia by using a percutaneous cardiopulmonary support system (PCPS) to resect a large, high-flow AVM. The efficacy and technical points of this method are discussed.

The PCPS, whose entire intraluminal surface was coated with heparin, was established through a transfemoral route. During resection of the AVM, a mean arterial blood pressure of 60 mm Hg and a mean body temperature of 30˚C were easily maintained by regulating the flow rate of the PCPS and by blood cooling. The activated coagulation time was maintained at approximately 250 seconds with a minimum systemic administration of heparin.

The authors report the case of a 30-year-old woman who presented with intraventricular hemorrhage and was diagnosed as having a large, high-flow AVM located in the left sylvian fissure. The AVM was fed by the left middle, posterior, and anterior cerebral arteries and drained by the many cortical ascending veins and the basal vein. The patient underwent surgery after hypotension and hypothermia had been induced via the PCPS method. Induced hypotension decreased the tension of the nidus and made its dissection easier. The AVM was totally resected and no hemostatic difficulties were encountered.

On the basis of the authors’ experience, they suggest that hypotension and hypothermia induced by using the PCPS is a powerful tool for the successful resection of large, high-flow AVMs.

KEY WORDS • arteriovenous malformation • surgical resection • hypotension • hypothermia • percutaneous cardiopulmonary support system

LARGE, high-flow arteriovenous malformations (AVMs) are among the most challenging lesions in neurological disorders. The key to successful surgical resection of AVMs is control of bleeding and cerebral swelling. To control intraoperative bleeding, surgical strategies, such as selection of the optimum operative approach and prior embolization, are as important as the surgical technique. In addition, induced hypotension is one of the most valuable means of controlling bleeding and swelling. In patients who harbor large, high-flow AVMs with multiple feeding vessels, induced hypotension shortens the time required for the dissection procedure because it decreases the tension of the nidus, thus facilitating its retraction and coagulation of the feeding vessels. Induced hypotension also lessens the degree of brain swelling.

We have used the percutaneous cardiopulmonary support system (PCPS) to maintain hypotension and mild hypothermia during resection of a large, high-flow AVM. We describe our method and discuss the technique and efficacy of the PCPS in AVM surgery.

The Percutaneous Cardiopulmonary Support System

Our PCPS consists of a centrifugal blood pump and a device whose entire intraluminal surface is coated with heparin (Carmede pack CCS-1; Medtronic Bio-Medicus, Inc., Eden Prairie, MN). After the patient is intubated, a Swan–Ganz catheter and a central venous catheter are placed via the internal jugular venous or subclavian route. To manage intraoperative cardiac dysrhythmias, an electrode catheter is also placed in the right ventricle for direct regulation through the venous route, and two insulated electrode paddles are affixed to the breast to apply elec-
Resection of an AVM using the PCPS

To introduce the PCPS via the transfemoral route, the right femoral artery and vein are dissected, exposed, and clamped. A small arteriotomy and venotomy are made. A No. 19 French cannula is placed in the right iliac artery using a guidewire and an introducer. A No. 21 French venous cannula is placed in the right atrium in the same manner. Figure 1 shows the patient prepared for extracorporeal circulation.

Anesthesia is maintained in the patient by administration of pentobarbital (2 mg/kg body wt/hour) and is supplemented by administration of isoflurane with nitrous oxide and oxygen. To prevent thrombus formation, heparin and nafamostat mesilate (6-amidino-2-naphthyl p-guanidinobenzonate; 3 mg/kg body wt/hour) are administered systemically during the procedure. The activated coagulation time is maintained in the range of 250 to 300 seconds. The dose of heparin administered is approximately 300 U/hour. Extracorporeal circulation is discontinued when total resection of the AVM is confirmed by intraoperative angiography. After removal of the cannula, the holes are sutured using nylon monofilament. Heparinization is reversed by using protamine sulfate to reduce the activated coagulation time to less than 150 seconds. A membrane–lung oxygenator can be used for 8 hours or more. If we exchange an oxygenator every 8 hours, this PCPS can be continuously used for 48 hours, which is the lifetime of a centrifugal blood pump.

During surgery, blood pressure can be controlled by regulating the flow rate of the PCPS; body temperature can be controlled by blood cooling or warming using a heat exchanger in the PCPS.

**Case Report**

This 30-year-old woman had experienced mild paresis of the right extremities since childhood. The patient had undergone computerized tomography (CT) scanning when she was 28 years old, which revealed an AVM at the left sylvian fissure. Because she had never experienced an episode that would indicate intracranial bleeding, she was followed at our outpatient clinic without treatment. However, she suffered an intraventricular hemorrhage when she was 30 years old.

**Examination.** The patient’s muscle strength was Grade 4 at the right upper and lower extremities. Postcontrast CT scanning and magnetic resonance (MR) imaging demon-

![Fig. 1. Illustration of the patient prepared for extracorporeal circulation using the PCPS. CV = central venous.](image)

![Fig. 2. Left: Postcontrast CT scan showing a large AVM in the left sylvian fissure, which appears as an irregular hyperdense mass. Center and Right: Magnetic resonance images showing axial (center) and coronal (right) sections demonstrating the extension of the AVM. Its largest diameter is 7 cm.](image)
strated an AVM located at the left sylvian fissure; its largest diameter was 7 cm (Fig. 2). The AVM was fed by the left anterior, middle, and posterior cerebral arteries and drained through many cortical veins and the deep venous system (Fig. 3). All cortical branches of the left middle cerebral artery acted as feeding arteries. The AVM was determined to be a high-flow type because perinidal normal vascular structures were not opacified on angiograms. Positron emission tomography scanning revealed that the perfusion pressure was decreased and the oxygen extraction fraction increased in the perinidal brain tissues (Fig. 4).

Intraoperative Management and Operation. To make dissection of the large, high-flow AVM easy and to control intraoperative bleeding, we planned to use the PCPS to maintain induced hypotension and hypothermia. We judged that all major feeding vessels could be exposed and controlled by opening the sylvian fissure and the basal cistern and that partial embolization of the nidus might increase the risk of bleeding. Therefore, we did not perform preoperative embolization.

Because the dissection procedures used to treat this large AVM were expected to require a great deal of time, even though induced hypotension was to be used, we planned to resect the AVM in two stages. In the first operation, we performed a large, left-side frontoparietooccipital craniotomy. We dissected the left sylvian fissure widely at the frontal side of the nidus and exposed the internal carotid artery, the anterior and middle cerebral arteries, the posterior communicating artery, and the anterior choroidal artery in the basal cistern. Then the dissected faces of the nidus were covered with expanded polytetrafluorethylene patches (Gore-Tex Soft Tissue Patch; W. L. Gore & Associates, Inc., Flagstaff, AZ) to protect against adhesion and the wound was closed. At the beginning of the second operation, which was performed the next day, a PCPS was introduced. During dissection of the AVM, we controlled and maintained the mean arterial blood pressure at 50 to 60 mm Hg, 60% of the patient’s normal blood pressure, by regulating the PCPS pump flow rate between 1.5 and 1.7 L/hour. The patient’s central body temperature was monitored with a thermometer placed in the jugular vein; it was maintained between 30° and 31°C to protect brain tissues from 40% hypoperfusion. After induction of hypotension, the tension of the nidus and draining veins was remarkably decreased and retraction was easy. Fragile feeding vessels could be coagulated and cut without rupture and the AVM nidus was totally resected. There were no hemo-
Resection of an AVM using the PCPS

static complications during the operation. The PCPS was used for 10 hours.

Postoperative Management and Course. A CT scan obtained after surgery demonstrated complete removal of the AVM nidus and an infarction at the left putamen (Fig. 5 left), which occurred as a result of occlusion of the lenticulostrate arteries. Complete resection of the AVM was confirmed on angiograms (Fig. 5 right).

Postoperatively, rewarming was accomplished at a rate of 1°C per day. Until the patient’s body temperature reached 36°C, vecuronium bromide was administered continuously. Her systolic blood pressure was maintained between 80 and 100 mm Hg for 10 days by continuous intravenous administration of nicardipine hydrochloride. The patient was sedated for 10 days by continuous intravenous administration of pentobarbital. Although her platelet count decreased postoperatively and necessitated platelet transfusion, there was no postoperative bleeding.

The patient’s hemiparesis worsened and her speech deteriorated postoperatively; however, rehabilitation gradually ameliorated her condition. By 6 months postsurgery, her muscle strength had recovered to Grade 3 in the right upper extremity and Grade 4 in the right lower extremity. She recovered to the point at which she could walk without assistance and speak without impairment.

Discussion

The difficulty encountered in surgical resection of large, high-flow AVMs is attributed to the difficulty of controlling the feeding arteries. All high-flow vessels should be interrupted before the main draining vein is cut. Although prior clipping by a staged operation or intravascular embolization has been used to control feeding vessels, it is difficult to interrupt all of the involved vessels by using these methods, especially in patients with large, high-flow AVMs. Therefore, the key to successful surgical resection of an AVM is intraoperative control of feeding vessels that may be hidden under the nidus or the voluminous draining veins.

We found induced intraoperative hypotension to be very useful during resection of an AVM. Because it reduced the tension of the nidus and the draining veins, we were able to confirm the existence of feeding vessels behind these structures. In addition, induced hypotension facilitates coagulation of tiny feeding arteries. Hypotension also helps to prevent brain swelling; however, it is difficult, using ordinary anesthetic methods alone, to maintain safe and adequate hypotension long enough to dissect a large AVM. In addition, the use of hypotension requires protection of the brain from hypoperfusion. The circulatory arrest technique, which has been used in surgeries of giant cerebral aneurysms, has a limited period of circulatory arrest (45–90 minutes). Therefore, we used the PCPS to control induced hypotension and hypothermia during the resection of a large, high-flow AVM. The patient discussed in the present report is the first case in which we used the PCPS to facilitate AVM surgery.

The main reason that the technique of inducing hypotension in the extracorporeal circulation has not been routinely used in AVM surgery is that it requires systemic heparinization, which carries with it the risk of uncontrollable bleeding. The circulatory arrest technique requires full-dose heparinization. However, the recent introduction of an extracorporeal circulation device whose entire intraluminal surface is coated with heparin makes it possible to keep the required systemic administration of heparin to a minimum when partial extracorporeal circulation is performed. If injury to brain tissue is minimal, one need not expect hemostatic complications. In addition, the PCPS is introduced easily and is minimally invasive, although perfusion support is required. Using the PCPS, blood pressure can be controlled by adjusting the pump flow and body temperature may be regulated by cooling the blood. Patients with preexisting cardiac or hematological disorders may not be candidates for surgery using this method. Introduction of the PCPS via the transfemoral route is not suitable in patients with atherosclerotic occlusive lesions of the iliofemoral arteries. We emphasize that the main disadvantage of this method is complicated preparation and that there are no major limitations or pitfalls.

We report that a combination of the sharp dissection technique, which leads to minimum injury of brain tissue, and the induction of hypotension using our PCPS makes it possible to resect large, high-flow AVMs safely without the occurrence of hemostatic complications.

References

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Manuscript received December 5, 1996. Accepted in final form April 18, 1997.
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